6.3 Cost Estimates

The developments embodied in the C-50 concept have resulted in significantly lower estimates of the total investment and operating costs than for the A-12 concept. The total estimated cost of produced plutonium is now $124 per gram compared to $230 per gram for A-12 as reported in Document No. LWS-24428. The following tables give investment and operating costs of the presently conceived C-50 and compare them with those of A-12 as reported in the June, 1952 Document No. LWS-24428. It will be noted that the breakdown of costs is similar to that used in the January, 1952 A-12 Status Report (Document No. LWS-12300). This breakdown is used since it presents more detail than the June report and enables a more direct comparison between this and previous reports.

6.31 Total Investment Cost

The total investment costs for both C-50 and A-12 are tabulated in Table VI. The striking reduction in estimated total investment costs of 50 per cent is due to the many technical developments and improvements in the MTA process during the intervening period. Among the most important of these developments are the use of higher frequency accelerator operation, the use of liquid metal target cooling, and the use of a chemical processing plant specifically tailored to meet MTA requirements. Also reflected in the reduction in the investment cost estimate is the present plan to purchase fabricated fuel and liquid nitrogen from outside sources. The A-12 estimate included the cost of construction of plants for producing these.

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TABLE VI

TOTAL CAPITAL INVESTMENT COST*

Item	C-50	A-12
1. Accelerator and Auxiliaries	$ 60,958,000	$118,000,000
2. Accelerator Building, Shielding and Utilities	7,578,000	15,050,000
3. Target and Target Facilities	54,790,000	72,400,000
4. Chemical Processing Plant and Auxiliaries	19,500,000	69,300,000
5. Fabricating Plant for Target Elements	---	17,300,000
6. Administration Area and Area Facilities	18,670,000	28,350,000
Total Design and Construction	$161,496,000	$320,400,000
Contingency	24,274,000	48,100,000
BASE INVESTMENT COST	$185,770,000	$368,500,000
General and Administrative Cost	9,285,000	16,500,000
Labor Factor	7,430,000	14,700,000
Weather Factor	3,715,000	7,300,000
TOTAL CONSTRUCTION COST	$206,200,000	$407,000,000
Start-up Cost	5,600,000	20,400,000
TOTAL CAPITAL INVESTMENT COST	$211,800,000	$427,400,000

* The number of significant figures shown in this and supporting tables was used for computational convenience. No such precision in the estimates should be inferred.

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6.32 Annual Operating Costs

The annual operating cost estimate for C-50, together with the comparable June, 1952, A-12 estimate for these items, is presented in Table VII. The 30 percent reduction in annual operating costs is largely due to the more compact and simplified plant embodied in the C-50 concept as compared to A-12. Also contributing to the reduction in estimated operating costs are reduced fuel fabrication charges, due to simplification in the form of the fuel elements and improvements made elsewhere in fabrication technology.

Other differences in the operating cost for C-50 and A-12 arise from the assumptions that fuel elements and liquid nitrogen are now purchaseable directly from outside sources. In contrast, A-12 estimates showed investment and operating costs on the basis of construction of fuel fabrication and liquid nitrogen production plants at the site.

A comparison of each of the items of annual operating cost for C-50 and A-12 is given in Appendix B-2, where specific reasons are given for the change in each item.

6.33 Cost of Plutonium Product

Table VIII summarizes the changes in operating and investment costs for C-50 as compared with A-12. (It is to be noted that the individual investment cost items given in Table VIII include for convenience the contingency, general and administrative cost, and labor and weather factors listed separately in Table VI.) These changes have resulted in a 46 percent decrease in the estimated cost of the plutonium product from $230 per gram for A-12 to $124 per gram for C-50. The product cost is computed from the ground rules and equation given in Appendix B-3.

A more detailed breakdown of the total investment costs for both C-50 and A-12 is presented in Appendix B-1. Also included in that appendix is a comparison of each of the detailed cost items for the C-50 and A-12 concepts showing specific reasons for the change in each item of the total estimated investment cost.

TABLE VII

ANNUAL OPERATING COST

Item		C-50		A-12
1. Labor		$ 4,830,000		$10,350,000
2. Power		9,630,000		11,800,000
3. Target Fuel				
a. Prefabricated Beryllium Primary		1,410,000		---
b. Prefabricated Uranium Spheres		4,330,000		---
c. Uranium Billets and Cladding		---		9,560,000
4. Nitrogen		1,540,000		---
5. Maintenance Materials		3,111,000		3,870,000
6. Supplies and Services		1,218,000		1,900,000
7. Chemical Processing		1,910,000		5,620,000
a. Labor	$770,000		$3,600,000	
b. Chemicals	240,000		280,000	
c. Underground Storage	520,000		600,000	
d. Maintenance Materials	200,000		880,000	
e. Utilities	180,000		260,000	
8. General and Administrative		1,403,000		1,900,000
9. Interest on Working Capital		48,000		---
TOTAL OPERATING COST		$29,430,000		$45,000,000

Note: The total annual operating cost for A-12 is the same as that shown in the June, 1952, status report. However, the breakdown of individual items has been changed to facilitate comparative studies with and without chemical processing.

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TABLE VIII

COMPARISON OF A-12 AND C-50 COSTS

	C-50	A-12	Remarks on Cost Decrease
TOTAL INVESTMENT COST (Including prorates, contingencies, etc.)			
Accelerator	$ 87,500,000	$169,000,000	Reduced accelerator size.
Target	70,100,000	92,000,000	Reduced target size.
Site Facilities	23,800,000	36,000,000	Reduced in size consistent with over-all plant size reduction.
Separations Plant	24,800,000	88,000,000	Combined and simplified plants; higher g/t level.
Fuel Fabrication Plant	None	22,000,000	Fabrication now subcontracted.
Startup Cost	5,600,000	20,400,000	Mark I experience.
Total	$211,800,000	$427,400,000	
ANNUAL COSTS			
Plant Fixed Charges at 16%	$ 33,890,000	$ 68,380,000	See above.
Inventory Charges at 16%	6,660,000	15,500,000	Smaller target.
Labor	4,830,000	10,350,000	Elimination of N_2 and Fabrication Plants; over-all plant simplification.
Power	9,630,000	11,800,000	Elimination of N_2 and Fabrication Plants; & Accelerator Auxiliary.
Target Fuel	5,740,000	9,560,000	Simpler fabrication requirements. Improved technology.
Nitrogen	1,540,000	Own Production Plant	Less expensive to purchase than produce at this lower required quantity.
Materials, Supplies & Services	4,330,000	5,770,000	General simplifications.
Processing Operating	1,910,000	5,620,000	Smaller, more simplified processing plant.
General and Administrative	1,400,000	1,900,000	General simplifications.
Total	$ 69,930,000	$128,880,000	
Product Cost ($/g)	$124	$230	

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APPENDIX A: Detailed Description of C-50 Concept MTA Plant

A-1 Accelerator Vessel and Auxiliaries

Some of the more important design characteristics of the C-50 Accelerator and Auxiliary Equipment were listed in Table IV (Section 6.2). The following is a detailed description of these items used as a basis for estimating purposes:

1. Accelerator Cavity Operating Characteristics

The C-50 linear accelerating cavity has been designed to operate at a frequency of 50 megacycles per second. The geometry is of the conventional resonant cavity drift tube type, similar to Mark I and A-12. The drift tube shells are considered to be of the Mark I type.

The selection of an operating frequency higher than that of A-12 is made possible by the recent availability of suitable power tubes, and the use of higher injection energy and stronger focusing. Calculations indicate that the improved focusing methods can maintain a beam diameter of about three to six inches and can achieve the necessary fields in drift tubes a few inches long. A small beam diameter permits a small drift tube outside diameter and shorter tubes; this permits a smaller cavity diameter and a higher radiofrequency. The operating frequency of 50 megacycles per second was selected for the present design since oscillator tubes will be available at this frequency with a rating of one megawatt continuous operation. The design of the accelerating cavity was carried out under the assumption that the drift tubes would have a constant outside diameter of two feet. This requires a cavity diameter at the particle-input end of 14.1 feet. The diameter decreases in a non-linear manner along the cavity to maintain an economical ratio of gap length to cell length (g/l). (Resonating cavity diameter decreases with increasing g/l, as the effect of drift tube loading is thereby reduced.) This effect decreases the cavity diameter to a minimum of 11 feet at the target end, with an average cavity diameter of 11.75 feet.

The initial acceleration to 1 to 2 Mev will be accomplished by a combination of electrostatic acceleration similar to the MTA Mark I ion source and radiofrequency acceleration either with the MTA Ion III type quarter-wave electrodes, or with a short, low gradient, linear accelerator in which the cell length is equal to the distance travelled by the ions in two wave lengths instead of one wave length. The final selection of the method will be determined by the knowledge of relative cost and efficiency which will be gained in the A-54 program. This selection will have only a very minor effect on over-all cost, but the estimates have been based on a 400 kilovolt d-c source and three quarter-wave, 50 megacycle electrodes.

The accelerator proper will increase the kinetic energy of the beam particles from 2 million electron volts to 500 million electron volts. The total accelerator length required for the energy increase is 2640 feet. In cavities of this length the control of the configuration or mode of the electric field is extremely difficult. In order to reduce the problem, the cavity has been divided into 26 separate cavities, known as mode cells, of an average length of 100 feet. Each cell is connected to the adjacent ones by evacuated tubes of about twelve inches in diameter through which the beam will pass. Each mode cell is actually an accelerator in itself and within limits may be made to operate independently of the other cells. Advantage is taken of this fact by operating certain mode cells at gradients different from the other units. Specifically, the first two mode cells at the low particle energy end of the machine where the gaps are small use an electric field gradient of 0.25 megavolts per foot. This low gradient reduces the tendency of sparking in the short gaps. Further, the last mode cell also operates at a gradient of 0.25 megavolts per foot since, even though the accelerating gaps are relatively large, outgassing products from the target may enter the last gaps and tend to produce sparking if a higher gradient were selected for this section. The remaining 23 mode cells operate at an electric field gradient of 0.35 megavolts per foot which is consistent with the gap lengths, in that sparking difficulties should not be encountered. Sectionalizing the accelerator serves the additional purpose of limiting the energy storage in an individual cavity to a relatively low value. Therefore, when a spark does occur the energy available for dissipation in the arc is small, and no damage to the drift tube faces should result.

2. Accelerator Cavity Design

Each vessel is complete with vacuum tight heads and is connected to the adjacent vessels by a tube of approximately twelve inches inside diameter. The vessels are constructed of one-half inch thick steel plate, 10 per cent copper clad, and are fabricated entirely by welding. Each vessel is stiffened against collapse by circumferential rings, which consist of wide flange tee bars welded directly to the steel shell. The spacing varies with the vessel diameter being closer at the injector end where the diameter is larger.

The vessels are constructed on wheels on a track extending from the shielding enclosure to a construction area outside. After each vessel is completed and vacuum tested it is rolled into position in the shielding enclosure. Then each vessel is anchored at the center to hold it against an earthquake load of one-tenth of its weight in any direction or against a couple tending to turn it about a vertical axis. The ends are free to move longitudinally to prevent stresses arising from changes in temperature.

It is necessary to cool the outer shells of the vessel in order to carry away the heat generated by losses in the copper cladding due to the radiofrequency current on the vessel walls. Longitudinal cooling ducts consisting of

1-1/4 x 1-1/4 x 1/4 inch angles are welded to the exterior of the vessel. These are placed longitudinally and are spaced approximately six inches on centers running the length of the vessel. Connections from the main cooling water headers to the vessel are made from a circular cooling header at each end of each vessel.

The drift tubes are introduced into the vessel through rectangular openings around the top center line. These openings are large enough to receive the drift tube and stem in one piece. The sides of the openings are braced against collapse by longitudinal box sections running the length of the vessel. Transverse members are placed between the openings in line with the vessel stiffening rings. The top flange of these members is on the same level as the top of the box sections so as to form a vacuum sealing surface. The drift tube stem and shell assembly is suspended from a spider integral with the stem and supported inside the longitudinal box sections. The positions of the drift tubes are adjusted by moving and shimming the spiders on the box sections. One drift tube is supported at each opening except near the injector end where the drift tubes are short. At this location more than one drift tube is supported at each opening.

The hole in the vessel shell for passage of the drift tube is fairly large. It is necessary to cover it in order to preserve the radiofrequency characteristics of the cavity. This is done by an OFHC copper plate attached to the stem of the drift tube at the line of the vessel shell and joined to the cladding by a suitable rf connection. The vacuum seal is made by a tight cover which goes over and outside the spider and bolts down to the copper flanges of the box section.

The vessel heads are flat and consist of circular copper-cladded steel disks welded to the shell. Each head is cooled by a 3/4 inch spiral pipe welded to the outside and connected to the inlet and outlet headers. Vacuum tight connections between the cylindrical vessels are provided and consist of a vacuum valve and a connecting tube of 12 inch inside diameter. The length between vessel heads varies from 2 to 7 feet and is designed to maintain the correct drift tube spacing. Changes in length of the vessels due to changes in temperature, pressure, etc., are taken up by deflection of the flat heads, which are supported at their centers by the connecting pieces. Adjustment is provided in order to tune the cavity to the proper frequency.

A manhole is provided for access into each vessel. Nozzles are welded to the side of the vessel approximately 2 feet above the horizontal center line for the introduction of the power amplifier transmission lines. Additional nozzles are provided for the necessary ion gauges, etc. The copper cladding is carried into all nozzles to a depth of at least twice the nozzle diameter to reduce field radiation.

3. Drift Tube Operating Characteristics

Solenoidal focusing magnets are built into the drift tubes to maintain a suitably focused beam. Present calculations indicate that this focusing method can maintain a beam diameter of from three to six inches with very moderate losses from stray particles. Control over the possible grazing loss of ions at the bore is available by variation of the focusing magnet current.

4. Drift Tube Design

The drift tubes are approximately 24 inches in diameter with a longitudinal opening of 3-inch diameter at the low-energy end. The drift tube bore diameter will increase to approximately 9 inches at the high energy end of the accelerator. The minimum drift tube length is approximately 12 inches. This length occurs at the injector end where the gap between the drift tubes is 4 inches.

The length of the drift tubes increases as a function of the particle energy so that at the target end of the accelerator the length of the last drift tube is approximately six feet. At this point the gap between drift tube faces is about 65 inches.

The tubes have an OFHC copper shell which is cooled with distilled water.

The drift tube proper is suspended by a water cooled stem having an OFHC copper shell and containing electrical connections to the drift tube magnets, and cooling water connections. The stem and tube are of one piece construction.

5. Radiofrequency Power for Accelerator

Power amplifier design is based on use of RCA 2332-C tubes which have been developed to deliver high power output at the frequency chosen for this accelerator. A rating of one megawatt of continuous power output is assumed at 75% efficiency. Each power amplifier is coupled to its mode cell by a transmission line.

As mentioned earlier the vessel has been divided into 26 mode cells. Since each mode cell is connected to adjacent ones by tubes of small diameter, it will be possible to maintain radiofrequency excitation in one mode cell independent of the others. To facilitate this flexibility of operation an effort has been made to keep the radiofrequency power amplifiers of one mode cell independent of others. In mode cells three through twenty-four, the cell length was adjusted to have an average radiofrequency power requirement of nine mega-

watts. This requires 12 megawatts of direct current power which is the rating assumed for an ignitron rectifier unit. In mode cells one, two, and twenty-six the electric field gradient is lower, the particle energy gain is low, and therefore power requirements are lower. In order to provide uniform construction and maintenance materials, similar 12 megawatt rectifier units are provided for the combined load of mode cells 25 and 26.

In order for proper particle acceleration to take place the radiofrequency voltage of each mode cells must be of the correct phase with respect to the others, which is accomplished by using radiofrequency power amplifiers rather than "oscillators". Phase and amplitude control over the voltage in all mode cells can be maintained by master control of all driver amplifiers. One driver amplifier supplies the excitation for all power amplifiers of a mode cell. It is possible by suddenly applying control signals to the driver amplifiers to obtain a very rapid rise of radiofrequency voltage in the mode cells. This rapid rise of cavity voltage is necessary to build up successfully from zero to the operating voltage level.

6. Direct Current Power Supply for Radiofrequency Power Amplifiers

The direct current supply for each vessel section is a 12 megawatt ignitron rectifier unit using tubes of the GL506-type which are presently used in the Mark I supply. Each direct current supply unit also includes a crowbar and reactor. A total of 24 of these units are arranged inside the accelerator building. The rectifier transformers, phase shifting transformers, and alternating-current reactors for each unit are located in outdoor fenced enclosures.

7. Beam Precessor or Diverger Unit

At the present time it is contemplated that either a precessor or beam diverger will be required to distribute the beam on the target.

The beam which emerges from the accelerator is focused to a small diameter by strong focusing in the drift tube magnets. Beyond the accelerator the beam naturally diverges, but the angle of divergence is small. To augment this natural divergence it is necessary to operate on the beam either with a precessor or a diverger.

A beam precessor is designed to bend the beam and sweep it across the target in a circular, spiral, or Lissajous pattern by means of a series of magnetic fields. The precessor does not change the shape of the beam appreciably.

A beam diverger accomplishes the same purpose as the precessor by diffusing the beam and spreading it out over the target without a sweeping action.

6

A diverger has been selected for preliminary estimates pending more complete information on beam particle dynamics.

8. Alternating-Current Power System

The system layout is based on four incoming 138 kilovolt power lines, capable of supplying a peak load of 397 megavolt-amperes. Three lines are capable of supplying the load without excessive losses thus insuring reliability.

Main power to the accelerator radiofrequency system is supplied through six 60,000 kilovolt-ampere 138 to 13.8 kilovolt transformers, each feeding four ignitron rectifier units of 12 megawatts each. By use of phase shifting transformers, a 72 phase rectifier system results.

The accelerator and the target auxiliary power is supplied through a separate transformer from the 138 kilovolt bus. Bus tie breakers are available for service outages of high or low voltage busses or transformer banks so as to insure continuity of service. Duplicate 13.8 kilovolt cables supply the distribution to the various motor control centers throughout the plant.

Generally speaking, the various pumps, blowers, and control devices have magnetic contactors protected with air circuit breakers located in the motor control centers. Essential emergency and shut-down auxiliaries have duplicate starting equipment connected to a source of power, independent of the main 138 kilovolt transmission lines. Manual or automatic throw-over, as required, is provided. No stand-by generating plant is provided, as this service could be supplied from a separate existing distribution system.

9. Distilled Water System

Distilled water is used to cool the vacuum vessels, drift tubes, injector and power amplifiers. The distilled water is in turn cooled by means of a heat exchanger using treated water as the cooling medium. A flow rate of 38,000 gpm is required for the vessel, drift tubes, and injector; and 14,000 gpm is required for the power amplifiers.

10. Treated Water System

Treated water is used to cool the mechanical vacuum pumps, rectifier heat exchangers, diffusion pumps, power transformers, air compressors, ventilation air coolers and refrigeration plant. A cooling tower capacity of about 525,000,000 Btu/hr is required to furnish 8,500 gpm of treated water required for equipment cooling plus that treated water to be used as the cooling medium for the distilled water.

11. Vacuum System

The vacuum system is used to evacuate the accelerator vessel so as to maintain an absolute pressure of approximately 10^{-6} mm Hg. The system consists of mechanical roughing pumps and mercury diffusion pumps, plus associated piping, valves, baffles, instruments and controls.

The pumping capacity of twenty-six 702 cfm pumps will lower the vessel pressure from atmospheric to 0.1 mm Hg in about 6 hours. The mechanical pumps are connected to a header to permit the use of less than the total number when backing up the diffusion pumps.

Diffusion pumps are of the linear type and are attached to flanges at the side of the vessel. Each pump is approximately 3 feet wide by 16 feet long. Each vessel requires one pump except that those at the injector and target ends require 2 to take care of the additional load from the injector and the target. These requirements are based upon direct extrapolation of Mark I operating experience. A series of water-cooled copper baffles extend across the openings in the longitudinal direction to prevent distortion of the rf field.

The mercury vapor for all the diffusion pumps will be furnished from a centrally located mercury boiler having about an 860 kw power requirement.

During pumpdown the vacuum vessel will be heated by passing steam through the cooling water lines. This will increase the surface outgassing rate and thus decrease the pumpdown time.

12. Liquid Nitrogen System

Liquid nitrogen is supplied by gravity flow to: (1) baffles installed between each diffusion pump and vacuum vessel nozzle, and in the vacuum system piping between the mechanical vacuum pumps and the diffusion pumps; (2) leak detection instruments; and (3) part of the ion gauges. The liquid nitrogen consumption of the entire system is estimated to be 3850 lbs per hour, based upon direct extrapolation of Mark I operating experience. All lines are insulated with vacuum jackets. No return lines are provided. Two 311 cfm mechanical vacuum pumps are provided to maintain the vacuum in the jacket.

13. Refrigeration System

A low temperature baffle is required between the jet of the vacuum system diffusion pump and the liquid nitrogen baffle. Refrigeration is supplied by an 87-ton plant which is of the closed cycle compression type with water-cooled compressors. It provides 35 F liquid Freon brine to the baffle.

14. Miscellaneous Auxiliaries

A mercury purification plant is included and consists of return and supply storage tanks, an intermediate supply tank, return and supply pumps, an oxifier, a filter and a sump pump. Mercury to be treated is lifted from the return storage tank by a small gear pump to the oxifier. Here it is agitated in the presence of oxygen, which results in the oxidation of impurities. From the oxifier, the charge falls by gravity to the filter unit where the lighter oxidized material rises during the next oxifier cycle. Finally, the initial charge is decanted into the supply storage tank by gravity.

The compressed air system provides compressed air at approximately 50 psi for instruments, valves and utility. The utility air distribution system provides an air outlet every 100 ft in the vacuum vessel building and within the vessel shielding.

The oil purification system removes moisture and sediment from the oil used in the mechanical vacuum pumps. Transfer pumps are provided.

A-2 Accelerator Building, Shielding, and Utilities

1. Vacuum Vessel Building

The Vacuum Vessel Building houses the power amplifiers and their associated direct current power supplies, consisting of rectifiers, direct current reactors, and crowbars. The power supplies for the drift tube magnets and the motor control centers for the mechanical auxiliaries are also located within the building. The building is a one-story structure attached to one of the shielding walls and is approximately 3100 feet long, 30 feet clear width and 12 feet clear height. It is of steel frame construction with asbestos siding board. Doors are provided at intervals along the outer wall for equipment access.

A one-story attached building approximately 150 feet long, 50 feet total clear width and 12 feet clear height is located near the center of the vacuum vessel building. This houses the control room, foremen offices, etc. There are also several additions approximately 50 feet long, 25 feet clear width and 12 feet clear height for electrical and mechanical shops, etc. The alternating current distribution system for the various supplies and motor control centers is located outside the building in fenced enclosures. The mechanical auxiliaries, such as the Kinney pumps, blowers for the oscillator cooling air, exhaust fan for the shielding, compressed air system, oil purifications system, refrigeration system, are located outdoors.

Most of the piping headers are outdoors adjacent to the accelerator building. These headers are carried on supports at the level of the roof. One cross trench under the accelerator building floor and leading into the shielding enclosure is provided for every two vacuum vessels. The cooling headers for the power amplifiers are located in the accelerator building in longitudinal trenches near the amplifiers. The common cooling headers for the vessel and drift tubes are inside the shielding enclosure.

2. Vessel Shielding

The vessel shielding houses the vessel, preaccelerator, injector, and diverger. It is approximately 3100 feet long, 24 feet wide and 18 feet high. The walls are constructed of poured-in-place concrete. The wall on the building side will serve as a common wall between the vacuum vessel building and the inside of the shielding. The other side consists of a counter fort wall which retains an earth bank of sufficient width to provide the necessary shielding. An access door is provided in the end wall at the injector end and two lateral access openings are constructed through the earth bank. The shielding roof consists of pre-cast concrete sections. These sections are removable in order to provide access for handling drift tubes, diffusion pumps, etc.

These items are handled by the traveling hoist on the gantry crane. The roof beams are 2 ft 6 in. deep at the injector end and increase in depth to 4 ft 3 in. at the target end. The joints between individual beams are protected by removable sheet-metal covers in order to make the roof water tight. The thickness of the common wall varies from 6 ft 3 in. at the injector end to 12 ft 6 in. at the target end.

3. Ventilation for Building and Shielding

As considerable quantities of heat are generated by electrical equipment in the vacuum vessel building, it is necessary to provide cooling and ventilation. It is also necessary to circulate air through the shielding during operation in order to limit the concentration of argon-41. To meet the shielding requirement approximately 4 changes per hour (55, 000 cfm) is circulated and a negative pressure maintained inside the shielding to prevent leakage of argon-41 to the outside atmosphere.

Ventilation and cooling is provided in the building by forcing air through water-cooled unit coolers spaced approximately at equal intervals along the building roofs. Sufficient cooling coils are provided to maintain the working area at a comfortable temperature. Air exhausted to the outside passes through holes in the outside building wall. Dampers are mounted in these holes so as to maintain a positive pressure in the building. Air is induced into the shielding through holes above the building roof level in the common wall. An outside duct connects these holes and is equipped with damper openings so that air may be taken into the shielding either from the building or from the outside. The air is exhausted from the shielding by means of two induced draft fans near the target and is discharged through a stack.

The building and shielding is heated when necessary by means of steam coils installed in the coolers mentioned above.

The cooling air for the power amplifier is circulated by separate blowers, exhausting into the building. The air is distributed through conventional ducts having a branch to each amplifier.

4. Gantry Crane

A gantry crane with a 50-ton hoist is installed on a track on top of the shielding. The main hoist is used for handling the roof blocks. In addition to this hoist, there is a 10-ton monorail running underneath the main bridge structure and extending out over the shielding embankment to a roadway. This roadway allows equipment to be hoisted out of the shielding and lowered on to a truck.

The gantry crane rails extend out over a loading area approximately 50 feet long at the injector end. Equipment inside the vacuum vessel building will be handled by means of rollers and lift trucks.

A-3 Target and Target Facilities

1. Target Description

(a) Beam Tube and Auxiliaries

The beryllium primary target is set back from the accelerator to the point where the beam has diverged to a diameter of six feet. The front of the primary acts as the vacuum or window membrane thereby eliminating the need for vacuum connections and seals in the neutron flux region between the primary and secondary target. A removable section of the beam tube allows the primary target and integral section of the beam tube to be removed to a decay storage pit. Area and facilities for delivery and handling the target are included.

(b) Primary Target and Cooling Circuit

The internal construction of the primary target is illustrated as part of the whole target assembly shown in Fig. 12. It consists of thin beryllium plates which are cooled by a sodium-potassium alloy (NaK). The depth of the target is approximately 36 inches to provide the full range of material required to stop the high energy deuterons. The target vessel of Inconel and stainless steel contains the beryllium plates and manifolds the coolant into and out of the plate matrix.

The heat absorbed by the coolant is transferred to cooling towers through an intermediate nonradioactive circuit of NaK. Heat exchangers and liquid-metal centrifugal pumps of somewhat conventional design are used. All the exchangers and associated equipment such as the dump tanks, pumps, cold-traps, and valves are of stainless steel. The equipment handling the radioactive NaK is installed in a concrete building having shielding walls approximately ten feet thick. The remainder of the equipment (NaK to water) is enclosed in a concrete building with walls approximately one foot thick to protect personnel from the hazard of liquid NaK leakage. Four parallel and independent circuits are provided, three of which are adequate for the operating heat load. The remaining circuit is for spare operation. An inert gas supply (helium) is required for gas blanketing the entire NaK system. Some refrigerating capacity is required for the cold-traps which scavenge the NaK. All circuits are provided with dump tanks.

The inventory of the primary target assembly is estimated to be about 6450 lbs of beryllium and 3000 lbs of NaK.

(c) Secondary Target and Cooling System

The secondary target is a vertical cellular structure 25 inches thick with a 16 ft diameter exposed face having an added peripheral zone to make a total diameter of 19 ft. The cellular arrangement of this target is two cells in depth and 21 cells over the width of the target. Cells are grouped in pairs for selective discharge but are fed from a common overhead supply line. The entire target structure is of stainless steel construction. As illustrated in Fig. 13, the coolant flows vertically through the secondary target bed.

A fast neutron reflector of one to three feet thickness of cast iron is positioned immediately behind the secondary target and has a built-in cooling system.

The fuel material consisting of one-half inch uranium spheres is random-packed within the cellular structure. Raw fuel is received at the target building in bulk amounts and is elevated to allow gravity feed to the target. Actual charging requires gas locks since the target operates with a positive pressure of inert gas. Facilities are required to measure the amounts of fuel charged to the target. As a means of avoiding the use of inaccessible mechanisms, the fuel is discharged from the bottom fuel traps by high-pressure jets of coolant and separated from the large volume of flowing coolant.

The heat released in the secondary target is removed in a manner similar to that employed in the primary circuit except that an emergency and shutdown cooling circuit is required. The operating circuit will consist of six parallel units including one spare. The shutdown equipment is isolated from the operating equipment.

(d) Lattice - Fuel Handling and Coolant Circuit

The water-cooled and moderated lattice consists of depleted uranium in the form of 2 inch aluminum-clad spherical fuel elements. The spherical form of the fuel elements is employed as a means for obtaining gravity or nonmechanized movement of fuel within the shielded target cell. The fuel assemblage (see Fig. 13) is a random-packed bed contained in a truncated conical annulus between the primary and secondary targets. The 12-inch-thick lattice is enclosed by a thermal neutron reflector consisting of two feet of water contained in an integral structure of alloyed aluminum. The discharge of fuel at the bottom of the lattice is accomplished by high-pressure water jets.

The lattice and reflector are sectionalized by the main stiffener rings of the structure. The sections so formed in the reflector region function as the inlet distributor and outlet collector manifolds for the cooling

water to and from the lattice bed. This arrangement provides a short longitudinal flow path within the lattice and also provides a means for balancing the flow to the lattice regions of higher heat flux. The cooling water is collected by an effluent riser to a constant head discharge. The overhead shielding tank constitutes part of the emergency cooling supply. (See Fig. 14.) The site location requires that the disposal of radioactive waste be minimized, hence a recirculating system is contemplated for the lattice cooling water. A 90 minute retention basin is expected to reduce activity to a non-shielded tolerance level before passing the water through heat exchangers and circulating pumps. It is anticipated that side-stream purification is necessary to prevent excessive build-up of long life activity in the cooling water and that a source of purified make-up water is required.

(e) Lag Storage Fuel Handling

Fuel elements discharged from the lattice are elevated for recirculation to the lattice or for discharge to lag storage. The latter facility consists of a large water-filled basin approximately 20 feet deep. Fuel elements are stored in suspended buckets at the bottom of this basin for sufficient time to allow radioactive decay of certain isotopes. The water acts as a shield for the gamma radiation and as a coolant for the stored fuel.

Fuel discharged from the bottom of the secondary target gravitates to a vessel for final separation of the fuel from the coolant. Then the fuel gravitates to equipment for removal of adhering coolant by means of gas or liquid scrubbing or removal by controlled chemical reaction. The clean fuel is elevated for recycling to the target or discharging to lag storage. The handling of the fuel at lag storage is similar to the method used for lattice fuel. Since the secondary fuel is unclad, it may be necessary to pass the fuel balls through a dipping tank to obtain a water-resistant coating. The purpose of this coating would be to prevent fission product activities from contaminating the water in the lag storage basin.

(f) Target Building and Helium System

The target structure is contained in a thirty foot cubical cell formed by massive concrete shielding walls. The concrete is given temperature protection by a cooled iron lining.

A helium system is contemplated as necessary for two purposes, viz., (1) to serve as a circulated atmosphere within the target cell for safety from NaK leakage as well as moisture removal, and (2) to provide an inert cover-gas within the closed NaK circuits.

Shops, offices, heating and ventilating equipment, vent stack, fuel receiving and storage, freight, control room, are also indicated on the layout drawings.

2. Target Process Description

The purpose of the target is to receive the deuteron beam from the accelerator in such a manner as to efficiently produce plutonium from depleted uranium fuel.

(a) Beam Characteristics

The accelerator is expected to produce a 500-Mev, 320 milliampere, deuteron beam focused to a diameter of three-to-five inches. The beam profile has been assumed to be plateau hyperbolic with peak-to-average current intensity less than ten-to-one. The beam diverges from the accelerator outlet to an approximate diameter of six feet at the primary target.

(b) Primary Target

The purpose of the primary target is to provide sufficient material for interaction of the incident deuterons. This target consists of 36 inches of material containing about 50-50 volume per cent of beryllium and NaK. Some deuterons lose their energy by ionization but others undergo nuclear events with beryllium or NaK nuclei. The interaction results in one of the original components of the deuteron being stopped while the other particle, known as a "stripped" neutron or proton continues in a forward direction with high energy. In addition, one or more nucleons may be expelled from the target nucleus. The majority of the neutrons created in this manner escape the primary target without further interaction and travel to the secondary target. The energy release by these processes is greatest at the front of the range, estimated to be 36 Mev/in. The Bragg peak at the end of the range is lower than the 36 Mev/in. This low attenuation, with the relatively large range makes it possible to have a small diameter target with nominal power density.

The primary target heat load has been estimated to be the deuteron beam energy minus the kinetic energy of the escaping high-energy neutrons. This estimate should be conservatively high as the energy carried away by "knock-out" neutrons should exceed the heat release from outside gamma absorption and neutron capture and moderation. On this basis, theoretical estimates predict 405 Mev per ampere-deuteron, corresponding to 130 megawatts (Mw) for the deuteron beam mentioned above.

The coolant becomes an intense source of gamma radiation after a short period of operation. In spite of the intensity of this radiation it is estimated that ten feet of concrete is adequate to shield all components of the coolant circuit. Of the radioactive isotopes which are produced by the deuteron and neutron bombardment, only K-38, Na-22, and Na-24 are of primary concern. K-38 and Na-24 reach a steady state concentration in the

coolant after a few days of operation. Na-22 has a 2.6 year half-life and requires more than 10 years of operation to reach steady-state. After 100 days of operation, the total activity of the NaK is approximately 0.8 curies per gram of NaK. Longer periods of operation mean slightly higher concentrations of Na-22 and, consequently, higher total activities. Continued build-up of Na-22 results in higher residual activities on shutdown since the K-38 and Na-24 essentially decay away after eight days of shutdown.

In addition to the above mentioned activities, others are produced by other high-energy neutron reactions with the parent sodium and potassium isotopes. No estimate of which radionuclides and to what levels they are produced can be made until reaction cross-section and flux parameters have been established.

The residual heat load of the primary target is not expected to be large enough to require cooling during shutdown of operation.

The life of the primary target has been assumed to be 1 year for the purpose of estimating the investment cost. Indications are that the expected life may be longer if the structural design of the target is adequate.

(c) Secondary Target

The basic function of the secondary target is to utilize the energy of the high-energy neutrons (up to 250 Mev) for the liberation of many nucleons of lower energy (0 to 10 Mev) through the processes of spallation and fission. A stripped neutron entering the secondary target may impart considerable energy to the uranium nucleus, often resulting in the immediate ejection of one or more nucleons. The remaining energy redistributes itself until successive nucleons accumulate sufficient energy to escape (about 7 Mev each), thus stabilizing the nucleus. Following this "evaporation" of neutrons, the residual nucleus may fission, releasing additional neutrons. The "evaporated" neutrons, with a new energy somewhat above that of the fission spectrum, then multiply by the more familiar process of fast neutron (1-10 Mev) induced fission of U-238.

The above processes result in a multitude of neutrons of fission energy or slightly higher. These neutrons undergo elastic and inelastic energy degradation processes, following which, some will be captured in the secondary target while others will escape to the lattice. A small number of neutrons are returned from the lattice to the secondary with a 1/E energy spectrum and at thermal energy, resulting in additional secondary target events.

The total number of neutrons released has been estimated with the aid of a statistical model of the nucleus which treats the nucleus as a gas of protons and neutrons. Basic cross-section data and neutron yields measured

with 190-Mev deuterons were also used. The analysis predicts 23 neutrons per 500-Mev deuteron for the NaK cooled Be-U system, exclusive of those created as a result of feedback neutron induced fissions.

The secondary target heat load can be approximated only. Neutrons boiled off in spallation events decrease the heat release in the subsequent fission of the excited nucleus to perhaps 100 Mev, while fast and thermal neutron induced fissions release about 180 Mev each. Using the same number of each type of neutron producing events as employed for the neutron yield estimate, a heat release of 1100 Mev per ampere-deuteron was calculated, including the kinetic energy of the incident high-energy neutrons. To this figure must be added 200 Mev released from fissions induced by neutrons, fed back to the secondary from the primary target and lattice. For the above current the heat load is 420 Mw giving an average power density in the fuel of 0.77 kw/in^3.

The distribution of the 420 Mw was assumed to follow the curve of creation of spallation neutrons by the high energy stripped neutrons, on the assumption that subsequent fast fissions would occur close to the place of birth of the exciting neutrons. Accordingly, the heat load should follow an exponential type curve with the maximum heating occurring at the interface between the primary and secondary target. The distribution of heat load in the secondary target is given in Fig. 15. The distribution which was used assumed a peak to average of 3.5 resulting in a peak power density of 2.7 kw/in^3.

The most severe cooling problem in the secondary target is encountered at the front face because of the high local rate of heat generation. However, adequate cooling can be accomplished by the NaK flow rate of 52,000 gpm which flows vertically through the target.

The plutonium production distribution within this target is not well known. It seems reasonable, however, to assume that the production and heat distribution have approximately the same shape. The extreme variation of production rate with depth through the target necessitates frequent mixing of the fuel elements to insure a more uniform production concentration at the time of discharge to lag storage.

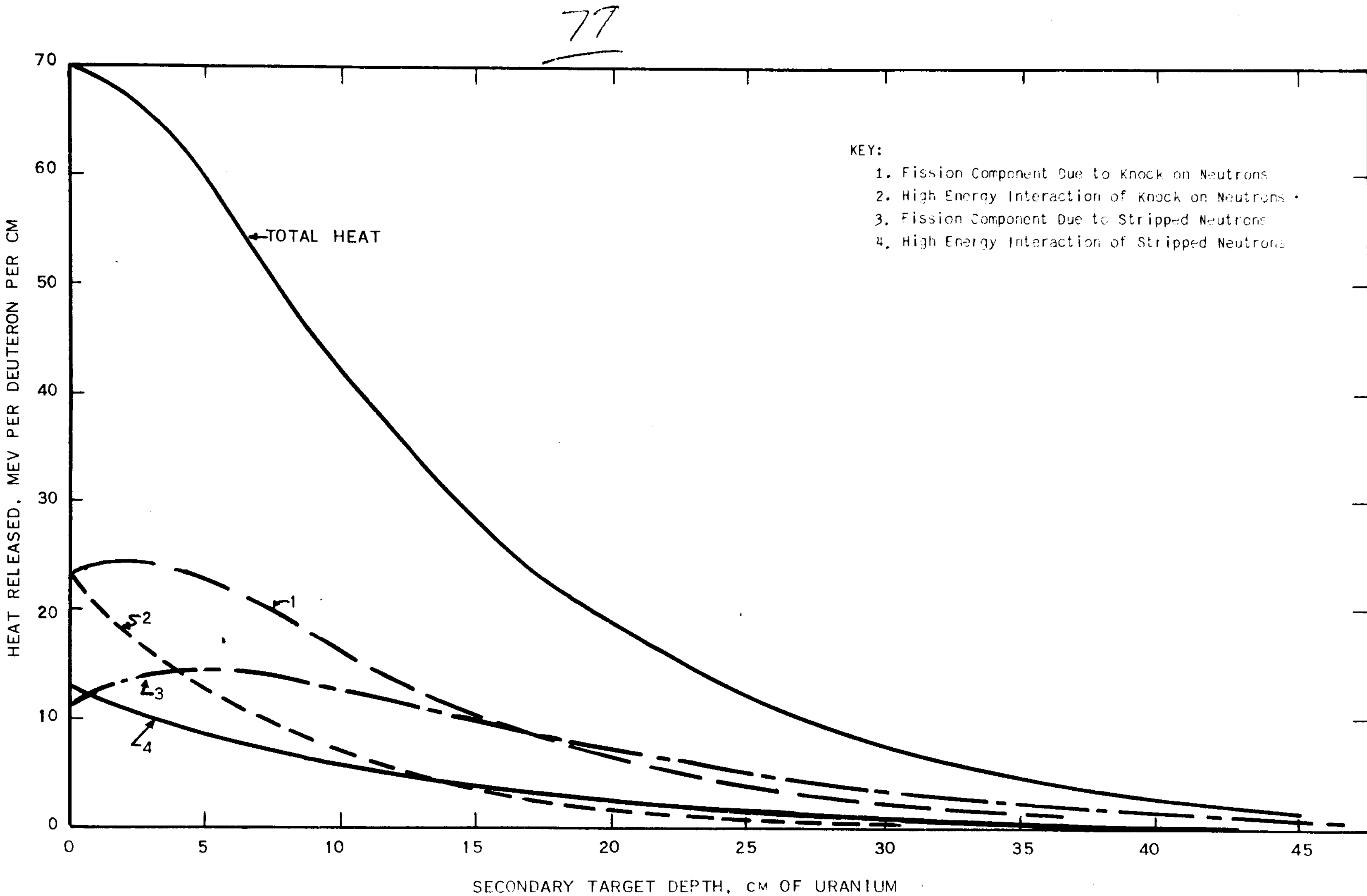

FIG. 15 - HEAT DISTRIBUTION IN SECONDARY TARGET - C-50 CONCEPT.

Experience with experimental systems bombarded by 190-Mev deuterons and extrapolation to higher energy indicates that about half of the total production will take place in the secondary target. For the over-all production of 564 kg/yr the secondary rate would be 0.912 kg per operating day. Upon this basis the average retention time for the fuel is approximately 294 days.

At shutdown, heat is released from the fuel by radioactive decay of U-239, Np-237, and the fission products produced. The magnitude of this heat load decreases with time. The capacity of the shutdown circuit will be 20.6 Mw for this heat load.

The coolant for the secondary is a source of intense radiation. The activity of the NaK is a result of the neutron irradiation of the stable potassium and sodium isotopes and the contamination by uranium fission products. The activity due to fission products is expected to be approximately 1/10 that produced by neutron activation. Depending upon the flux and cross-section parameters, Na-24 and K-38 will probably be the greatest sources of gamma radiation in the NaK. It is expected that ten feet of concrete is adequate shielding for this activity.

(d) Lattice

Neutrons escaping from the secondary target act as a source for the fertile material in the form of a water-moderated uranium lattice. Neutrons are captured during the slowing down process and after thermalization. Although the uranium is depleted a significant increase in the net number of neutrons available arises from the thermal fissioning of U-235, thereby increasing the plutonium production and the lattice heat load.

The production distribution through the depth of the lattice is maximum within a few centimeters from the inner lattice face. In addition there undoubtedly is an axial distribution, but only qualitative remarks are possible at this time. It appears that, due to the shape of the lattice with respect to the secondary target, the axial distribution should be rather uniform. A peak-to-average production ratio of two for the axial direction seems reasonable. For uniform product level, frequent mixing of the fuel elements is necessary. The distribution of the heat load should be very similar to the production distribution described above. The heat load is due

primarily to thermal fissions of U-235 and the small amount of subsequent fast fissioning of U-238. Since these processes are fairly well known, the lattice heat load can be stated with some degree of reliability as 275 Mw, provided that 50 per cent of the original neutrons escape the secondary target. This heat which is transferred to the circulating water as previously described, causes a peak power density of 1.2 kw/in.^{3}. The maximum fuel temperature has been estimated to be about 950 F inside the 2 in. diameter aluminum-clad uranium balls.

The heat release per unit volume during shutdown of the lattice is essentially the same as that in the secondary. Since water is used as the coolant, it is necessary to provide prompt cooling by means of a standby tank until the shutdown system can be put on the line. An emergency system for 12.5 Mw, sized for the energy release at one minute after the beam has been turned off, and 2 hours capacity is contemplated. A shutdown cooling capacity of 8.2 Mw also is provided for normal shutdowns.

(e) Handling and Lag Storage

After removal, the lattice and secondary target fuel elements must be put into lag storage for a period of 50-100 days. This will allow essentially all the neptunium to decay and the activity to decrease to a practical level for handling to chemical processing.

Fuel balls are removed from the targets in batch quantities, but are sent from lag storage to chemical processing at a steady rate. Because of these two requirements, the quantity of fuel in storage varies between a maximum and minimum value such that, on the average, the fuel will have been stored for the appropriate length of time. Proper programming of fuel removal from the targets reduces the average amount of fuel and product in storage.

A-4 Chemical Processing Plant and Auxiliaries

The chemical separations plant for the recovery of plutonium and uranium from fuel discharged from the accelerator is based upon the Purex process as developed by ORNL, HW, KAPL, ANL, etc. This process employs tributyl phosphate dissolved in water-immiscible solvent as an extraction agent to separate both plutonium and uranium from extraneous waste materials.

After a period of radioactive decay, secondary target and lattice fuels are dissolved in nitric acid. Two cycles of solvent extraction are then employed to separate the product metal solutions and an aqueous fission product stream which is neutralized and stored underground. The decontaminated uranyl nitrate is thermally decomposed with the resulting uranium oxide being shipped from the site for reconversion to the metallic state. Product plutonium is shipped from the site in stainless steel containers in the form of an aqueous nitrate solution for conversion elsewhere to plutonium metal buttons.

The process design was developed to include only features with a sound experimental foundation and for which a high assurance of operability existed. Design provisions are considered to be liberal and could probably be reduced by more detailed study and additional operating experience at other installations.

The flow diagram in Fig. 16 presents an outline of the process. This scheme employs separate structures for process operations prior and subsequent to the first product extraction, each appropriately designed for the greatly different levels of radioactivity to be handled. Highly radioactive operations contained in the first building are abbreviated to a minimum of process steps, continuous in nature and with low holdup. The balance and majority of the process plant is housed in a lightly shielded structure that approximates the methods and costs of conventional chemical industry. Both buildings employ direct maintenance procedures which, in conjunction with the abbreviation of highly radioactive operations, greatly reduces construction cost. The "high-activity" building is integrated with lag storage facilities to permit conveyor transfer of fuel, saving railroad and handling costs. This building has 3 foot concrete shielding and contains the dissolving, I-A Purex extraction, and high level waste concentration steps with appropriate hold tanks. A continuous "trickle-type" dissolver is proposed with fuel spheres admitted periodically through a chute and acid addition controlled to obtain a product solution suitable after dilution for direct feed to a Purex I-A extractor. Continuous, integral dissolving is assumed; calculations show that the additional aluminum results in only a minor increase in total waste volume. Various alternatives are available for the dejacketing of cladding and the removal of possible protective coatings required by lattice spheres in lag storage. "Head-end" treatment is eliminated as indicated by Purex

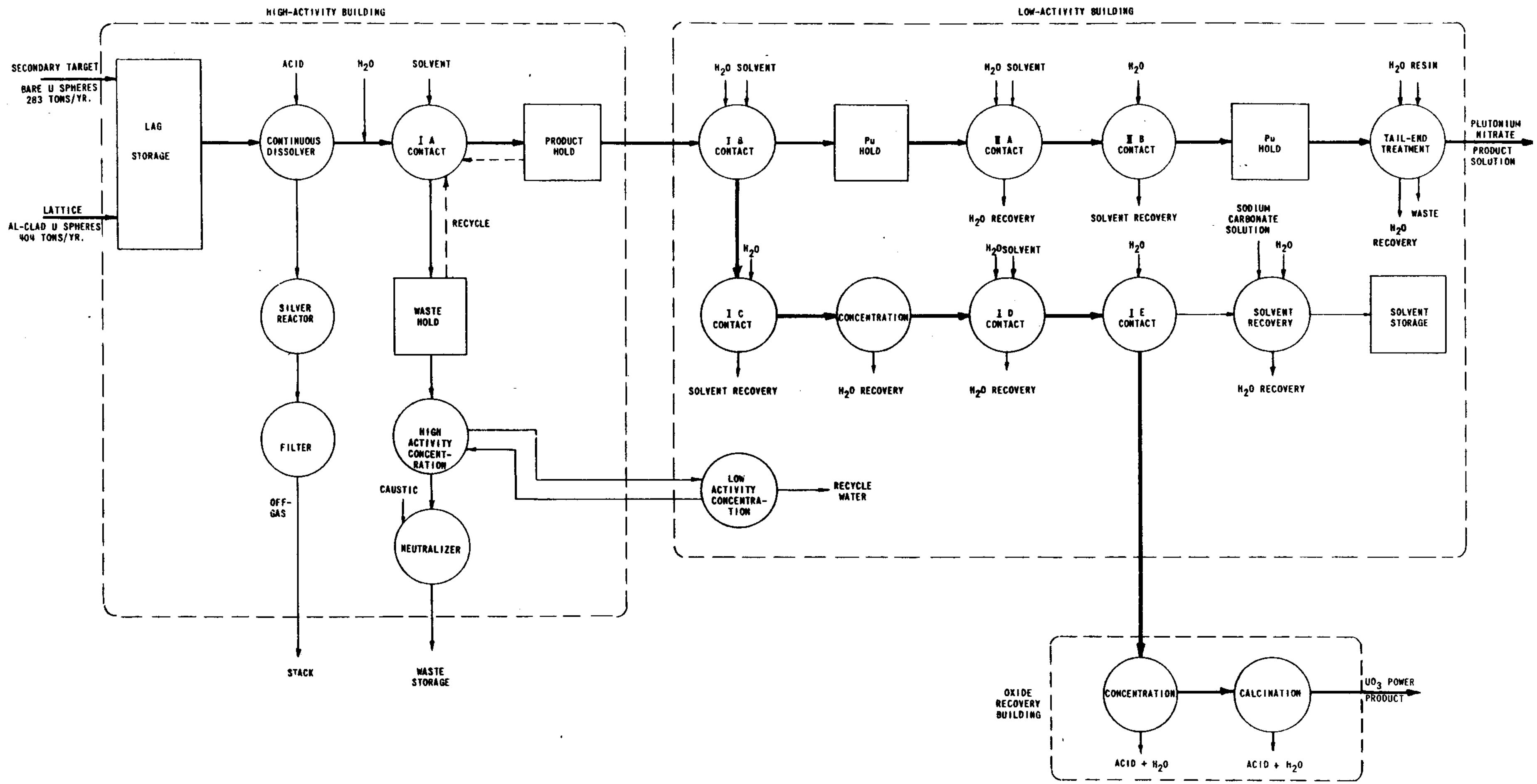

FIG. 16 - PROCESSING PLANT FLOW DIAGRAM - C-50 CONCEPT.

process improvements and lower purity specifications. "Tail-end" treatment is provided, although further research may indicate that it would not be required in order to meet required purity specifications on the plutonium product. Process units would be designed so that all eventualities can be handled without the use of a remote-operated crane. Equipment and cells would be designed to facilitate remote-operated decontamination with inclusion of appropriate spray heads and drains. Cells would be lined with steel. Equipment and lines would be carefully designed to avoid recesses and "dead" surfaces. The design philosophy is to accomplish in place the work that is presently done in the decontaminating shops of Redox and Purex installations. This is done by the installation in the high-activity building of a complete spare line of process equipment separated by a full shielding wall from the other equipment. This will permit process operations to be continued at full throughput while the idle line is decontaminated and repairs or replacements are made.

An equipment cell might be flooded with water for temporary radiation shielding, and extension tools employed for minor maintenance or repairs. Major maintenance or repairs would be made in place after complete decontamination of the idle process equipment. Casks or applied surface shielding might be used for removal of defective or incompletely decontaminated equipment. Future experience with direct maintenance procedures, as in the Idaho Chemical Processing Plant, should further define the most desirable design innovations in order to allow economical maintenance.

The hold tanks for extract waste (IAW solution) would be batch sampled and monitored for product loss before being sent to underground waste storage which is provided for one year's full scale operation. The extract solvent (IAP solution of uranium and plutonium) would flow under continuous monitoring to another set of storage tanks sized for a 24-hour holdup. Radiation counters of appropriate sensitivity could be installed in both the transfer line and the tanks. Any off-specification material from this operation would be automatically diverted to a "hot" tank for later recycle and reworking. A further check on activity level could be made in sampling of the storage tanks prior to being fed into the second process building. Adequate safeguards could be installed to lower the risks to acceptable limits for gross activity passing these storage tanks.

The product stream as it leaves these storage tanks will have been decontaminated by a factor in excess of a thousand (activity estimated to be in the order of 0.02 curies/gal). This activity level can be feasibly handled in a lightly-shielded, remotely-operated, directly-maintained plant. Experimental data shows that proven decontamination methods can adequately and quickly decontaminate equipment exposed to this level of activity. Thus the balance of the processing plant (Purex IB and IC contactors, second uranium cycle, second plutonium cycle, etc.) can be placed in a structure

several fold cheaper than orthodox "canyon" buildings. Direct maintenance and light (1 foot of concrete) shielding, would permit inexpensive construction and the use of more conventional and standard equipment. In general, maximum use would be made of standard construction techniques developed by the conventional chemical industry. Freedom would be obtained for process changes after operations were started, and the process would not be "frozen" as in conventional remote-maintenance plants. The use of light shielding and thin walls would permit piping changes that are all but impossible in the present Redox and Purex plants. In view of the potentialities and versatility of the MTA, this flexibility is most appropriate and desirable.

A-5 Administration Area and Area Facilities

1. Water System

The existing water system at Weldon Spring, consisting of wells, treating plant and main distribution system is considered adequate, after repairs, to meet utility and cooling tower makeup requirements. Although total cooling water system costs were not consolidated in the C-50 estimate total the amount allowed for these is $13,000,000 distributed as follows:

Accelerator and Auxiliaries	$ 2,900,000
Target and Target Facilities	10,100,000
	$13,000,000

If completely new water facilities were required [illegible] the total cost is estimated at about $12,000,000.

2. Electric Distribution System

A completely new power supply and distribution system is necessary to meet the requirements of the accelerator and auxiliaries. The cost of this system is estimated to include incoming 138 kilovolt switchgear and transformers to step down the voltage to 13.8 kilovolts, the voltage at which power is supplied to the accelerator and its auxiliaries and to the shop and administration area.

3. Area Facilities Buildings

The area facilities buildings consist of an administration building; garage, cafeteria; personnel, purchasing and hospital building; firehouse; warehouses; machine, electrical and electronic shop building; carpenter shop, and a security building. These buildings are located at the north-east corner of the site, and they are of steel frame and insulated asbestos construction.

4. Miscellaneous

Approximately ten miles of new macadam roads and six miles of new railroad trackage are required, much of this construction is over irregular terrain.

Fencing and security lighting surrounds each facility as a unit and also encloses the entire state. This is necessary because of the irregular terrain.

A heating and distilled water plant is included to provide heating and distilled water makeup requirements.

APPENDIX B; C-50 Cost Estimates

B-1 Investment Costs

Estimated costs for A-12 were reported in the January 1952, Status Report on MTA, (Document No. LWS-12300). These were revised slightly downward by a June, 1952, supplemental informal report entitled, "Objectives of a Continued MTA Research & Development Program" (Document No. LWS-24428). In the discussion and cost estimates that follow, costs of the presently conceived C-50 are compared with those of A-12 as reported in the June, 1952, supplement.

It will be noted that the breakdown of costs is similar to that used in the January, 1952, A-12, Status Report. This breakdown is used since it presents more detail than the June report and enables a more direct comparison between this and previous reports.

1. Total Investment Cost

The total investment costs for both C-50 and A-12 are tabulated in Table I. These totals have been compiled from the Design and Construction Costs shown in Tables II, III, IV, V and VI, with percentages added to take account of General and Administrative expense, as well as weather and labor conditions in the St. Louis area. The percentages used are as follows:

Contingency	-15 per cent of Design and Construction Cost to arrive at base investment cost.
General and Administrative Cost	- 4-1/2 per cent of the Base Investment Cost for A-12--5% of Base Investment Cost for C-50.
Labor Factor	- 4 per cent of Base Investment Cost.
Weather Factor	- 2 per cent of Base Investment Cost.

TABLE VI

TOTAL CAPITAL INVESTMENT COST*

Item	C-50	A-12
1. Accelerator and Auxiliaries	$ 60,958,000	$118,000,000
2. Accelerator Building, Shielding and Utilities	7,578,000	15,050,000
3. Target and Target Facilities	54,790,000	72,400,000
4. Chemical Processing Plant & Auxiliaries	19,500,000	69,300,000
5. Fabricating Plant for Target Elements	---	17,300,000
6. Administration Area & Area Facilities	18,670,000	28,350,000
Total Design and Construction	$161,496,000	$320,400,000
Contingency	24,274,000	48,100,000
BASE INVESTMENT COST	$185,770,000	$368,500,000
General and Administrative Cost	9,285,000	16,500,000
Labor Factor	7,430,000	14,700,000
Weather Factor	3,715,000	7,300,000
TOTAL CONSTRUCTION COST	$206,200,000	$407,000,000
Start-up Costs	5,600,000	20,400,000
TOTAL CAPITAL INVESTMENT COST	$211,800,000	$427,400,000

DEDUCTION FOR OMISSION OF CHEMICAL PROCESSING PLANT		
Chemical Processing Plant Cost Including Gen. and Adm. Cost Labor Factor and Weather Factor(-)	24,891,000	
Start-up Cost for Chemical Processing Plant and Auxiliaries(-)	604,000	
TOTAL CAPITAL INVESTMENT COST EXCLUDING CHEMICAL PROCESSING PLANT AND AUXILIARIES	$186,305,000	

* The number of significant figures shown in this and supporting tables was used for computational convenience. No such precision in the estimates should be inferred.

In the succeeding Tables IX through XIII certain consistent variations between the A-12 and C-50 estimates exist which are reviewed here to avoid repetition.

a. Technical Services (Engineering Design and Construction Supervision)

For preliminary estimates of this type technical services usually estimated as a percentage of "Construction Cost." Both A-12 and C-50 Technical Services were estimated in this manner. A-12 technical services were estimated to be about 11 per cent of "Construction Cost" ("Design and Construction Cost" less "Technical Services.") Since the cost of C-50 is less than one-half that of A-12, the total amount available for Technical Services would be less than one-half that of A-12 if the same percentage were used. In a project of this type, the development of design information represents a substantial part of the cost of Technical Services without regard to the quantity of labor and material involved. For this reason, 15 per cent of "Construction Cost" has been allowed for Technical Services in the C-50 estimate.

b. Indirect Construction Costs and Direct Prorates

The procedure for estimating C-50 differs from that used for A-12 in that Indirect Construction Costs have been revised to more closely conform to the AEC Construction Accounting Manual dated July, 1952. In the C-50 estimate 28 per cent of Direct Construction Cost has been allowed for Indirect Construction Cost as compared to an average of 14 per cent for A-12. For C-50 "Indirect Construction Costs" includes all costs shown in the following A-12 categories: (1) Indirect Construction Cost, (2) Direct Prorates, and (3) that portion of each individual Direct Cost item which represents costs now defined as indirect construction. Specifically, indirect construction costs are now considered to include the following:

Description	% of Direct Labor
Temporary Construction Facilities:	
Temporary office, etc.	1%
Temporary utilities	1%
Scaffolding	1%
Equipment rental	12%
Sub-Total	15%

(Cont'd) Description	% of Direct Labor
Overhead	
Small Tools	4%
Consumable supplies	5%
Field Office expense (Supervision, office overhead, etc.)	8%
Material handling	1%
Unallocated labor	2%
Payroll taxes	15%
Premium travel and showup time	0%
Fee or profit	25%
Home office supervision and overhead	10%
Completion bond	3%
Sub-Total	73%
Total Indirect Cost	88%

Because of this estimating revision, it should be noted that when comparing C-50 individual direct costs with those of A-12, the C-50 costs will appear directionally lower, even in those cases where the costs of material and labor are the same for both estimates.

2. Investment Cost for Accelerator Vessel and Auxiliaries

The cost estimate for the C-50 accelerator vessel and auxiliaries is presented in Table IX together with the corresponding estimate of A-12 made for the June, 1952, report. The cost differences resulting from the improved C-50 concept are discussed below:

a. Accelerator Vessel, Tanks and Other Containers — C-50: $ 4,951,000; A-12: $13,550,000

The higher frequency of the C-50 design results in the average vessel diameter being around 12 feet as compared to about 50 feet for A-12. However, the C-50 vessel is approximately 75 per cent longer than A-12. The combined result of these changes is a sizeable decrease in volume, weight, and cost as compared to A-12.

b. Refrigerated Baffles and Other Exchangers — C-50: $ 983,000; A-12: $1,536,000

Since the C-50 vessel has much less surface area than A-12, the vacuum system requirements are substantially smaller than those of A-12. The decrease in diffusion pump capacity resulting from decreased vacuum system requirements has reduced the area of refrigerated baffles necessary.

TABLE IX

INVESTMENT COST

ACCELERATOR VESSEL AND AUXILIARIES

Item	C-50	A-12
1. Technical Services	$ 7,950,000	$ 11,000,000
2. Indirect Construction Costs	10,600,000	6,200,000
3. Accelerator Vessel, Tanks and Other Containers	4,951,000	13,550,000
4. Refrigerated Baffles and Other Exchangers	983,000	1,536,000
5. Mechanical Pumping Equipment and Drivers	219,000	192,000
6. Diffusion Pumps	859,000	2,911,000
7. Piping	1,412,000	5,695,000
8. Steel and Concrete Structures	222,000	738,000
9. Insulation	113,000	150,000
10. Drift Tubes	3,396,000	10,384,000
11. Oscillators and Transmission Lines	5,706,000	8,419,000
12. Oscillator Power Supply	9,400,000	23,318,000
13. Other Electrical Equipment, including Injector plus Spare Injector	5,640,000	9,359,000
14. Painting, Testing, and Services	332,000	1,700,000
15. Miscellaneous	2,067,000	4,500,000
16. Instrumentation	3,956,000	3,692,000
17. Refrigeration, Material Handling and Other Equipment	2,652,000	6,156,000
18. Tuning	500,000	3,500,000
19. Direct Prorates	-	5,000,000
TOTAL DESIGN AND CONSTRUCTION COST	$60,958,000	$118,000,000

Other heat exchanger costs are essentially the same as those of A-12.

c.	Mechanical Pumping Equipment and Drivers	C-50: $219,000 A-12: $192,000

The capacity of the Kinney pumps required for A-12 totaled 30,000 cfm, but the corresponding requirements for C-50 is only 19,000 cfm. The effect of the decrease in cost due to a smaller volume is offset by the fact that a faster pump-down time is planned for C-50.

d.	Diffusion Pumps	C-50: $ 859,000 A-12: $2,911,000

The A-12 concept was to have 600 - 32 inch diameter pumps, whereas C-50 will have 28 - 3 ft x 16 ft linear pumps. The substitution of linear for round pumps has resulted in a lower pump cost per unit of capacity, as well as greatly simplifying the associated piping and considerably reducing liquid nitrogen consumption in its distribution system.

e.	Piping	C-50: $1,412,000 A-12: $5,695,000

The smaller number of pumps in C-50 has greatly reduced the cost of diffusion pump inlet valves which are included under this item. The reduced required capacity of the vacuum system has also reduced the cost of vacuum and refrigeration piping.

f.	Steel and Concrete Structures	C-50: $222,000 A-12: $738,000

The reduction in vessel size and amount of piping, pumps, etc., results in a decrease in cost of these structures.

g.	Insulation	C-50: $113,000 A-12: $150,000

Essentially the same as A-12.

h.	Drift Tubes	C-50: $ 3,396,000 A-12: $10,384,000

The drift tubes for C-50 are smaller and less complicated than those for A-12. A-12 had 62 drift tubes that averaged 9 ft in diameter and ranged between 8 and 23 ft in length. The C-50 would have 368 drift tubes, all 2 ft in diameter, with lengths ranging approximately from one ft to six ft.

The greatly decreased size of the C-50 drift tubes has resulted in a substantial decrease in cost even though the number required has increased.

i. Oscillators and Transmission Lines — C-50: $5,706,000; A-12: $8,419,000

Design simplifications made possible through the knowledge gained in the construction and operation of Mark I and L-2 oscillators will result in a lower cost.

j. Oscillator Power Supply — C-50: $ 9,400,000; A-12: $23,318,000

At the time the A-12 report was prepared, rectifiers for the oscillator power supply were estimated at a unit cost based on Mark I experience. The Mark I rectifiers carried large development costs and were given conservative capacity ratings. More recent experience with the L-2 cavity, supported by conclusions reached through consultations with manufacturers, indicate with reasonable assurance that the future cost of these rectifiers, when purchased in large quantities, may be reduced to approximately one-third of the original cost. Furthermore, the A-12 estimate included a Dummy Load estimated to cost approximately $3,000,000. Due to an improved system for rf control, a Dummy Load is not believed to be necessary for C-50. These are the primary factors contributing to the cost difference between C-50 and A-12 for this item.

k. Other Electrical Equipment Including Injector Plus Spare Injector — C-50: $5,640,000; A-12: $9,359,000

The C-50 has a smaller auxiliary power requirement due to decrease in the size of the vacuum and other systems. This results in a substantial decrease in the cost of this item.

l. Painting, Testing and Services — C-50: $ 332,000; A-12: $1,700,000

The cost of testing the much smaller vacuum system of C-50 is much lower than for A-12. Because of the smaller physical size of the installation other service requirements such as painting and general testing have also been reduced.

m. Miscellaneous — C-50: $2,067,000; A-12: $4,500,000

This item has been decreased to maintain the same percentage of total as used for A-12.

n. Instrumentation — C-50: $3,956,000; A-12: $3,692,000

Operation of Mark I has shown that instrumentation requirements per unit of electrical equipment are greater than those originally provided for in the A-12 estimate. This results in the C-50 cost being slightly more than A-12.

o. Refrigeration, Material Handling, and Other Equipment — C-50: $2,652,000; A-12: $6,156,000

The decreased vacuum system requirements have reduced the cost of the Freon refrigeration system. The A-12 liquid nitrogen requirement was so large that a nitrogen plant was included in the design and comprized the major cost for these items. As the C-50 requirement is lower, nitrogen will be purchased from outside suppliers, thus eliminating the cost of this plant from the capital cost estimate.

Since the A-12 drift tubes were much larger than C-50, it was necessary to remove them by a costly remote-operated car which traveled lengthwise inside the vessel. The C-50 drift tubes being much smaller, can be removed through the top of the vessel by the overhead gantry crane.

p. Tuning — C-50: $ 500,000; A-12: $3,500,000

Tuning Costs are less for C-50 than for A-12 primarily because the scheme of dividing the accelerator vessel into several smaller vessels greatly simplifies this operation.

3. Investment Cost for Accelerator Buildings, Shielding and Utilities

The cost estimates for the accelerator buildings, shielding, and their utilities are presented in Table X together with the corresponding estimates of A-12 made in June, 1952. The cost differences resulting from the improved C-50 concept are discussed below:

a. Heating and Ventilating Systems, Overhead Crane, etc. — C-50: $417,000; A-12: $833,000

The accelerator building for C-50 has approximately one-third the volume of the A-12 building. Also the use of rectifiers instead of motor generator sets, and the location of a substantial amount of equipment outside have reduced the heat dissipated in the building. These factors have reduced the cost of building, heating and ventilating equipment. The C-50 shielding has approximately one-eighth the volume of the A-12 shielding, and therefore requires less ventilating equipment for the removal of argon-41.

TABLE X

INVESTMENT COST

ACCELERATOR BUILDINGS, SHIELDING AND UTILITIES

Item	C-50	A-12
1. Technical Services	$ 988,000	$ 1,250,000
2. Indirect Construction Costs	1,645,000	920,000
3. Heating and Ventilating Systems, Overhead Crane, etc.	417,000	833,000
4. Piping	137,000	150,000
5. Shielding Walls and Roof, Miscellaneous Steel and Concrete Structures	2,383,000	4,840,000
6. Shielding Pit and Other Foundations	707,000	2,155,000
7. Accelerator Buildings and Refrigeration Building	917,000	2,956,000
8. Power and Lighting	148,000	296,000
9. Dummy Load	---	600,000
10. Miscellaneous	236,000	550,000
11. Direct Prorates	---	500,000
TOTAL DESIGN AND CONSTRUCTION COSTS	$7,578,000	$15,050,000

b. <u>Piping</u> C-50: $137,000
A-12: $150,000

The decreased size of C-50 building and shielding as discussed below has reduced the cost of piping required for the building proper.

c. <u>Shielding, Walls and Roof</u> C-50: $2,383,000
A-12: $4,840,000

The A-12 shielding structure was approximately 1500 ft long, 80 ft wide and 85 ft high. The C-50 structure is approximately 3100 ft long, 24 ft wide and 18 ft high. In both cases the wall thicknesses are approximately the same. The decrease in the size of shielding, which has been made possible by reduction in the diameter of the vessel, results in the concrete required for the C-50 shielding being approximately one-third of that required for A-12.

d. <u>Shielding Pit and Other Foundations</u> C-50: $ 707,000
A-12: $2,155,000

Since C-50 used rectangular diffusion pumps attached to the side of the vessel, the need for a shielding pump pit has been eliminated. Also the costs of foundations for C-50 are less than A-12 due to the reduced size of the structure.

e. <u>Accelerator Building and Refrigeration Building</u> C-50: $ 917,000
A-12: $2,956,000

The A-12 accelerator building was a three-story reinforced concrete structure, 50 feet wide by 54 feet high and 1500 feet long designed to resist bomb blast. The C-50 accelerator building is a steel frame structure 30 feet wide by 12 feet high and 3100 feet long. The smaller size and more simple design of the C-50 building accounts primarily for the decrease in cost. This smaller size is made possible because of the somewhat less amount of auxiliary equipment required, the fact that more equipment can be placed outside when no consideration is given to bomb blast restrictions, and the fact that a less conservative attitude has been taken toward the housing of certain mechanical equipment such as vacuum roughing pumps in view of experience with the L-2 cavity. Another factor contributing to the lower cost of C-50 is that the A-12 estimate provided for a separate refrigeration building to house a nitrogen plant which has been eliminated from the C-50 design as mentioned earlier, (Note: The saving due to the elimination of bomb blast protection amounts to about 1-3/4 million dollars.)

f. Power and Lighting — C-50: $148,000; A-12: $296,000

The substantially decreased size of the accelerator building and shielding has reduced the power and lighting requirements.

g. Dummy Load — A-12: $600,000

Not required for C-50 due to an improved system for rf control.

h. Miscellaneous — C-50: $236,000; A-12: $550,000

This item was decreased to maintain the same percentage of the total as used in the January and June reports for A-12.

4. Investment Cost for Target and Auxiliaries

The investment cost for the C-50 target, lattice assembly and associated auxiliaries are presented in Table XI together with corresponding estimates of A-12.

The A-12 target consisted of a uranium primary and secondary which were water-cooled and designed for high-peak-energy beam characteristics. It consisted of a vacuum vessel 35 feet long and 18 feet in diameter located at the bottom of a large water tank. The C-50 target has a beryllium primary, is cooled with liquid metal, and is designed for a lower-peak energy beam made possible by the high frequency of the C-50 accelerator. These features permit the use of a much smaller target and a consequent reduction in cost which is explained in detail below:

Target and Lattice Assembly

a. Target Vessel — C-50: $ 400,000; A-12: $3,000,000

The A-12 had a very large and costly target vessel. The C-50 has no target vessel but costs do include a short exterior section of the vessel which is small in diameter and which has an isolating gate.

b. Primary and Secondary Targets — C-50: $3,010,000; A-12: $8,300,000

As mentioned earlier, the over-all physical arrangement of the targets has been greatly simplified for C-50 which largely accounts for the decrease in cost of this item. Another factor contributory to the lower cost is that charges for initial load of uranium fuel and cladding were included

under this item for the A-12 report whereas similar costs for C-50 have been included under inventory charges as explained in Appendix B-3, Section 5-A.

c. Lattice and Shielding — C-50: $ 2,200,000; A-12: $11,500,000

The A-12 lattice consisted of large moveable "C" frames with graphite reflectors which were very costly. The C-50 lattice is much simpler in that it is a small lattice in a stationary double shell structure with water reflector. The A-12 method of handling lattice fuel involved a costly under-water transfer system and equipment for handling massive structures. The C-50 lattice fuel handling system involves moving spherical fuel with comparatively light and simple equipment. Shielding for A-12 was water contained in a very large tank. Shielding for C-50 is provided by the massive concrete building walls, cost of which is included under Item 7 ("Target Building and Crane"). The only C-50 shielding costs appearing in this item are those for thermal protection of building concrete.

d. Control and General Equipment — C-50: $1,100,000; A-12: $1,500,000

The C-50 costs for this item are less than for A-12 because of reduced complexity and decreased over-all size of the target.

e. Target Building and Cranes — C-50: $1,950,000; A-12: $6,500,000

The target building for A-12 was very large (90 x 250 ft). Since this building was designed as a bomb proof structure the wide span resulted in very costly construction.

The C-50 target building is considerably smaller (30 x 30 ft). Even though the C-50 building walls are massive concrete to serve as shielding, the small size of the building results in it being a less expensive structure.

Target and Lattice Auxiliaries

a. Primary Cooling System — C-50: $3,000,000; A-12: $9,760,000

Decreased cost is due to decreased cooling load, (130 Mw for C-50 as compared to 330 Mw for A-12).

TABLE XI

INVESTMENT COST

TARGET AND AUXILIARIES

Item	C-50	A-12
TARGET AND LATTICE ASSEMBLY		
1. Technical Services	$ 1,750,000	$ 4,500,000
2. Indirect Construction Costs	3,030,000	3,580,000
3. Target Vessel	400,000	3,000,000
4. Primary and Secondary Targets	3,010,000	8,300,000
5. Lattice and Shielding	2,200,000	11,500,000
6. Controls and General Equipment	1,100,000	1,500,000
7. Target Building and Cranes	1,950,000	6,500,000
8. Direct Prorates	---	1,360,000
DESIGN AND CONSTRUCTION COSTS (Target and Lattice Assembly)	$13,440,000	$40,240,000
TARGET AND LATTICE AUXILIARIES		
1. Technical Services	5,400,000	2,050,000
2. Indirect Construction Cost	9,260,000	2,120,000
3. Primary Cooling System	3,000,000	9,760,000
4. Secondary Cooling System	10,200,000	4,430,000
5. Lattice Cooling System	5,100,000	6,610,000
6. Heating, Ventilating and Air Conditioning	500,000	750,000
7. Vacuum System	---	450,000
8. Helium System	700,000	---
9. Emergency Cooling Sys. & Make-up Supply	1,450,000	1,500,000
10. Waste Water Disposal System	840,000	2,500,000
11. Auxiliaries Bldg., Shielding & Cranes	4,600,000	4,100,000
12. Decay Storage Facilities	300,000	---
13. Direct Prorates	---	1,200,000
DESIGN AND CONSTRUCTION COSTS (Target and Lattice Auxiliaries)	$41,350,000	$35,470,000
TOTAL TARGET AND LATTICE ASSEMBLY AND AUXILIARIES	$54,790,000	$75,710,000
Less initial charge for U and Zr	---	-3,310,000
NET DESIGN AND CONSTRUCTION COST	$54,790,000	$72,400,000

b. Secondary Cooling System — C-50: $10,200,000; A-12: $ 4,430,000

Increased cost is due to the increased cooling load (420 Mw for C-50 as compared to 180 Mw for A-12).

c. Lattice Cooling System — C-50: $5,100,000; A-12: $6,610,000

Decreased cost is due to decreased heat load (275 Mw for C-50 as compared to 310 Mw for A-12).

d. Heating, Ventilating and Air Conditioning — C-50: $500,000; A-12: $750,000

Since the C-50 target and building are smaller than A-12, the cost of these items is less.

e. Vacuum System — A-12: $450,000

None required for C-50 due to elimination of large target vacuum vessel.

f. Helium System — C-50: $700,000

Because of the use of NaK cooling for C-50, a helium system is required to provide an inert atmosphere in the target cell and throughout the NaK system. This was not required for the A-12 water cooled target.

g. Emergency Cooling System and Makeup Supply — C-50: $1,450,000; A-12: $1,500,000

Equipment required for C-50 is very similar to that of A-12 and costs are approximately equal.

h. Waste Water Disposal System — C-50: $ 840,000; A-12: $2,500,000

Decreased cost is due to the substitution of NaK for distilled water cooling of the primary and secondary. The amount shown for this item is for disposal of the lattice cooling water only.

i. Auxiliaries, Buildings, Shielding and Cranes — C-50: $4,600,000; A-12: $4,100,000

Costs are approximately equal for very similar items.

j. Decay Storage Facilities C-50: $300,000

In the June A-12 estimate, the cost of these facilities was included under "Primary and Secondary Targets" and "Lattice and Shielding".

5. Investment Cost Estimates for Chemical Processing Plant and Auxiliaries

Chemical processing costs for C-50 and A-12 are compared in Table XII. Basic changes result in C-50 costs being considerably less than those for A-12.

The A-12 estimate for a 804 ton/year plant with separate handling of primary-secondary and lattice uranium was scaled directly from the cost experience of conventional plutonium recovery plants, whose massive plant structure and large investment costs place a high premium upon capacity.

The C-50 costs for a 687 ton/year, single-line plant were estimated from a process design specifically tailored to MTA requirements. This design exploits the simplications permitted by lower purity specifications for recovery of depleted uranium as compared to material intended for enrichment. In conjunction with other design changes, simplifications were obtained that result in a unique abbreviation of highly radioactive operations and that appreciably reduce total structural costs. The revised process design includes the following departures from prototype reactor processing methods.

a. Plant integration to shorten transfer distances, and fuel transfer by conveyor.

b. Substitution of "tail-end treatment" for "head-end treatment".

c. Continuous fuel dissolution.

d. Abbreviation and segregation of highly radioactive operations in a specialized process unit, with a directly operated crane and a separately shielded spare process unit.

e. Use of operating safeguards to prevent gross radioactivity passing to units processing lightly radioactive material.

f. Use of light shielding, standard equipment, and more conventional construction for a separate processing unit reserved for lightly radioactive operations.

g. Use of in-place decontamination and direct-maintenance procedures.

TABLE XII

INVESTMENT COSTS

CHEMICAL PROCESSING PLANTS AND AUXILIARIES

Item	C-50 Breakdown	C-50 Total	A-12
1. Technical Services		$ 2,500,000	$ 6,800,000
2. Indirect Construction Costs		3,900,000	3,300,000
3. Separations Plant		7,050,000	47,000,000
a) High Activity Building			
1) Process equipment, piping, instr., controls and special equipment	$2,010,000		
2) Building, utilities & services	790,000		
b) Low Activity Building			
1) Process equipment, piping, instr., controls and special equipment	3,630,000		
2) Building, utilities & services	1,220,000		
4. Oxide Recovery Plant		1,150,000	850,000
a) Process equipment, piping, instrl., controls & special equipment	800,000		
b) Building, utilities & services	350,000		
5. Site Evaporator		----	840,000
6. Auxiliaries		3,390,000	7,810,000
a) Site utilities	1,900,000		
b) Maintenance Shops	400,000		
c) Gas Waste Disposal	600,000		
d) Tank Farm	190,000		
e) Process equipment spares	300,000		
7. Initial Underground Storage		550,000	400,000
8. Laboratory		360,000	----
9. Direct Prorates		----	2,300,000
TOTAL DESIGN AND CONSTRUCTION COST		$19,500,000	$69,300,000

These features have been operationally demonstrated and require little additional development. Further description and details of the C-50 Separations Plant Estimate are presented in Section A-4 of the appendix.

A possible alternative to building this C-50 processing plant would be to utilize a portion of the capacity of a large conventional processing installation if needs, methods, and location were compatible. Costs were obtained for a standard single-line Purex plant of 2400 ton/year capacity, and prorated on a straightline basis to cover the throughput of the C-50 concept. Prorated plant investment and annual operating costs were computed to be $19,940,000 and $2,150,000 as compared to $19,500,000 and $2,010,000 estimated for the integral plant. Thus, similar economic conclusions are obtained for this potentiality.

6. Investment Cost for Administration Area and Area Facilities

The investment cost for the administration area and area facilities for both C-50 and A-12 are summarized in Table XIII.

a. Roads, Railroads and Fencing — C-50: $1,500,000; A-12: $1,520,000

The requirements for both A-12 and C-50 are essentially the same.

b. Accelerator Cooling Water System — C-50: $1,550,000; A-12: $1,880,000

The requirements for both A-12 and C-50 are essentially the same except for a slight reduction due to the decreased vessel skin losses of C-50. (Note: Cooling towers and other cooling facilities for the target are included under the target section.)

c. Electrical Distribution — C-50: $4,872,000; A-12: $7,000,000

The C-50 has fewer auxiliaries than A-12 due to the decreased size of the vacuum and other systems and site facilities. This has resulted in the total average electrical load of C-50 being approximately 15 per cent less than that of A-12 with a consequent decrease in the cost of electrical distribution facilities.

d. Other Utilities — C-50: $700,000; A-12: $780,000

The requirements for both A-12 and C-50 are practically the same.

TABLE XIII

INVESTMENT COST

ADMINISTRATION AREA AND AREA FACILITIES

Item	C-50	A-12
1. Technical Service	$ 2,440,000	$ 1,700,000
2. Indirect Construction Costs	3,480,000	4,700,000
3. Roads, Railroad and Fencing	1,500,000	1,520,000
4. Accelerator Cooling Water System	1,550,000	1,880,000
5. Electrical Distribution	4,872,000	7,000,000
6. Other Utilities	700,000	780,000
7. Buildings	1,887,000	4,320,000
8. Boiler Plant and Distillation Facilities	750,000	3,150,000
9. Disposal Facilities	700,000	1,263,000
10. Tools, Equipment and Miscellaneous	791,000	1,087,000
11. Direct Prorates	----	950,000
TOTAL DESIGN AND CONSTRUCTION COSTS	$18,670,000	$28,350,000

e. Buildings C-50: $1,887,000
A-12: $4,320,000

C-50 costs are less due to the use of frame instead of concrete structures, decreased shop requirements because of the smaller physical plant, and fewer operating personnel.

f. Boiler Plant and Distillation Facilities C-50: $ 750,000
A-12: $3,150,000

The A-12 estimate provided for a sizeable distillation plant to provide distilled water for the target. The target distilled water requirements have been substantially reduced, due to design changes, which results in a decrease in the cost of the distillation plant. The A-12 estimate also provided for a standby electric power plant which is no longer considered to be justified, as this service is available from a separate existing distribution system. This item now includes only a small steam generating plant to satisfy heating requirements and the reduced distillation facilities.

g. Disposal Facilities — C-50: $ 700,000; A-12: $1,263,000

This cost has decreased due to the use of NaK cooling for the C-50 primary and secondary targets. On A-12 these were water cooled and contributed to the total waste water.

h. Tools, Equipment and Miscellaneous — C-50: $ 791,000; A-12: $1,087,000

The cost of these items for C-50 is less due to the smaller amount of equipment to be maintained.

7. Investment Cost Estimate for Target Fuel Fabrication Plant

The C-50 target includes a prefabricated beryllium primary, a secondary of unclad uranium spheres, and a lattice of aluminum-clad uranium spheres. It is believed to be appropriate and desirable that this material be supplied commercially by a subcontractor. The entire cost is therefore included under operating costs.

By comparison, the June, 1952, A-12 case included a $22,000,000 plant for the fabrication of zirconium-coated plates and aluminum jacketed rods from uranium billets.

It is believed that the use of the spherical shape for the secondary and lattice uranium will permit the subcontractor to cast the uranium directly into spheres rather than into the intermediate billet. Elimination of both a recast step and close dimensional tolerances has resulted in appreciable savings.

8. Start-up Costs

The start-up costs for the current C-50 and June, 1952, A-12 cases are tabulated in Table XIV. Discussion of the various items follows:

a. Labor — C-50: $ 2,415,000; A-12: $10,350,000

The decrease in start-up labor costs for C-50 as compared with A-12 results from the belief that less operating personnel will be required as discussed in Section 6.5. Also, a shorter period is assumed for start-up and the hiring and training of operators, six months for C-50 versus about one year for A-12. The assumption of a shorter start-up period is based on operating experience with Mark I.

The above factors combine to result in a sizeable reduction in start-up labor cost.

TABLE XIV

START-UP COSTS

Item	C-50	A-12
1. Labor	$2,415,000	$10,350,000
2. Power	842,000	1,100,000
3. Supplies	1,300,000	3,150,000
4. Travel	200,000	200,000
General and Administrative	239,000	700,000
TOTAL STARTUP, EXCLUDING CHEMICAL PROCESSING	$4,996,000	$15,500,000
5. Chemical Processing		
a. Labor	385,000	3,600,000
b. Chemicals	40,000	100,000
c. Underground Storage	87,000	----
d. Maintenance Materials	33,000	700,000
e. Utilities	30,000	300,000
General and Administrative	29,000	200,000
TOTAL STARTUP, INCLUDING CHEMICAL PROCESSING	$5,600,000	$20,400,000

Note: The total start-up cost for A-12 is the same as that shown in the June 1952 A-12 report. The above breakdown has been made to facilitate comparative studies with and without chemical processing.

b. Power — C-50: $ 842,000
A-12: $1,100,000

One month of normal operating power is estimated as the start-up requirement for C-50. This is approximately the same as for A-12. However, the normal C-50 power requirements are less than those of A-12.

c. Supplies — C-50: $1,300,000
A-12: $3,150,000

Two months of operating costs for nitrogen, maintenance materials, supplies and services is estimated as the start-up requirement for C-50. The reduction from the A-12 requirement is based on the reduction in size of the facilities and the shortened start-up period.

d. <u>Travel</u>

C-50:	$200,000
A-12:	$200,000

Travel requirements are the same for both concepts.

e. <u>Chemical Processing</u>

C-50:	$ 604,000
A-12:	$4,900,000

The start-up costs are estimated to include six months of operating labor and two months each of the normal operating requirements for chemicals, underground storage, maintenance materials, and utilities with general administrative costs of 5 per cent.

B-2 Annual Operating Costs

The annual operating costs for C-50, together with the comparable June, 1952 A-12 estimate for these items are tabulated in Table VII. Costs, exclusive of chemical processing, are tabulated separately to facilitate comparative studies. Differences between C-50 and A-12 for these costs are explained below:

1. Labor — C-50: $ 4,830,000; A-12: $10,350,000

Although the annual average labor rate has increased from $6,000 for A-12 to $7,000 for C-50, a substantial reduction in labor cost is anticipated for C-50. This is due to the following:

a. Elimination of the on-site fuel fabrication plant;

b. Elimination of the on-site nitrogen plant;

c. A general reduction in manpower requirements due to the decreased size and simplification of the installation as well as less conservative estimates supported by experience on Mark I.

2. Power — C-50: $ 9,630,000; A-12: $11,800,000

Power costs for both C-50 and A-12 are based on an operating factor of 85 per cent and a rate of 3.8 mills per kwh. This rate was derived from a study made by the Union Electric Company in 1951 on furnishing power for an MTA plant at Weldon Spring. The decrease in power requirement for C-50 is due to omission of fabrication plant, nitrogen plant and a reduction in accelerator auxiliaries and some site facilities. Total power requirements for C-50 are 335 megawatts.

3. Target Fuel — C-50: $5,740,000; A-12: $9,560,000

The annual cost for the C-50 primary beryllium target is based on replacement once per year without credit for possible beryllium salvage. A unit cost of $200 per lb for beryllium was used. This cost is felt to be conservative, and would probably be considerably less for purchases in quantities as large as this. Fuel for the A-12 secondary and lattice, required on-site fabrication of purchased metal billets. As mentioned earlier, it is believed that for C-50, an off-site subcontractor can cast the uranium metal directly into spheres without an intermediate billet. Cost of conversion of zero value depleted UF_6 to metal spheres is estimated at $2.92 per pound for

unclad uranium spheres and at $3.32 per pound for aluminum-clad uranium spheres. These prices are based on the interpretation of cost tables furnished by the AEC covering "Interim Projected Unit Costs", natural uranium. Adjustments were made to these costs for conversion to spheres rather than billets. This is a considerable reduction from the June, 1952 A-12 estimate which was based on purchase of metal billets, including cladding, at a cost of approximately $6.00 per pound of uranium throughput to an on-site fabrication plant.

4. Nitrogen C-50: $ 1,540,000

The A-12 case included an on-site nitrogen plant. For the C-50 case it is assumed that nitrogen will be purchased on subcontract at $0.048 per pound. This unit cost is based on Mark I experience. Annual nitrogen consumption is based on a vacuum system operating factor of 95 per cent as compared to the 85 per cent over-all operating factor. This assumes that the vacuum will be maintained in the vessel during two-thirds of the shutdowns.

5. Maintenance Material C-50: $ 3,111,000
A-12: $ 3,870,000

The decrease in maintenance materials for C-50 is due to the over-all smaller size of concept.

6. Supplies and Services C-50: $ 1,218,000
A-12: $ 1,900,000

The reduction in the estimate for this item reflects the over-all decrease in number of personnel and size of facilities. Utilities such as telephone, teletype, and fuel oil are included here.

7. Chemical Processing C-50: $ 1,910,000
A-12: $ 5,620,000

The decrease in this item results from the process revisions and the simplified plant structure estimated for C-50.

8. General and Administrative C-50: $ 1,403,000
A-12: $ 1,900,000

General and administrative costs were taken as 4-1/2 per cent of operating costs for the A-12 case and 5 per cent of operating costs for the C-50 case.

9. <u>Interest on Working Capital</u> C-50: $ 48,000

The required working capital for the plant operation has been taken as one month's operating cost. Interest on this working capital has been taken at 2 per cent per annum in accordance with the economic ground rules set forth in Appendix B-3. This item was not included in the economic analysis of the A-12 concept.

TABLE VII

ANNUAL OPERATING COST

Item		C-50		A-12
1. Labor		$ 4,830,000		$10,350,000
2. Power		9,630,000		11,800,000
3. Target Fuel				
a. Prefabricated Beryllium Primary		1,410,000		-----
b. Prefabricated Uranium Spheres		4,330,000		-----
c. Uranium Billets and Cladding		-----		9,560,000
4. Nitrogen		1,540,000		-----
5. Maintenance Materials		3,111,000		3,870,000
6. Supplies and Services		1,218,000		1,900,000
7. Chemical Processing		1,910,000		5,620,000
a. Labor	$770,000		$3,600,000	
b. Chemicals	240,000		280,000	
c. Underground Storage	520,000		600,000	
d. Maintenance Materials	200,000		880,000	
e. Utilities	180,000		260,000	
8. General and Administrative		1,403,000		1,900,000
9. Interest on Working Capital		48,000		-----
TOTAL OPERATING COST		$29,430,000		$45,000,000
DEDUCTION FOR OMISSION OF CHEMICAL PROCESSING PLANT				
Labor, Supplies and Services	(-)	$ 1,910,000	(-)	$ 5,620,000
General, Administrative and Working Capital Interest	(-)	100,000	(-)	250,000
TOTAL OPERATING COST EXCLUDING CHEMICAL PROCESSING, PLANT AND AUXILIARIES		$27,420,000		$39,130,000

Note: The total annual operating cost for A-12 is the same as that shown in the June, 1952 status report. However, the breakdown of individual items has been changed to facilitate comparative studies with and without chemical processing.

B-3 Cost of Plutonium Product

1. Ground Rules

The above computations were made by applying CR&D's understanding of the AEC economic ground rules set forth in Mr. D. P. Herron's memorandum entitled "Revision of Basis for Production Cost Projections", dated June 9, 1952. From these rules, the annual charges for investment in wholly Government-owned facilities are as follows:

a. Working Capital

Interest on working capital and warehouse materials at 2 per cent. This amount has been included in the annual operating cost for convenience.

b. Investment in Plant and Equipment

Amortization of plant and equipment at the rate of 15 per cent per year; this assumes a straight line amortization formula for a useful plant life of 6-2/3 years. Interest on total investment in plant and equipment and +++ "other operations required to put the process into initial operation" +++, at one-half the rate charged on working capital; namely, 1 per cent. This, in effect, is an interest rate of 2 per cent charged against the average value of the plant.

c. Source and Fissionable Material Inventory

An annual rental, or incentive charge, of 16 per cent for the entire plant inventory of source and fissionable material. This material to be valued at its "projected cost of production". This includes plutonium product held up in the target, lag, storage and processing. Inventories of source and fissionable material are shown in Figure 11.

2. Basic Formula

Based on the above ground rules, the production costs have been computed as follows:

$$\emptyset = \text{Cost of Product } (\$/\text{grams})$$

$$= \frac{\text{Investment Cost } (0.16) + \text{Inventory Value } (0.16) + \text{Annual Operating Cost}}{\text{Annual Production}}$$

$$= \frac{(C + S)\, f + (I_u + I_p)\, f^1 + N}{R}$$

Definitions

C = Total construction cost ($)

S = Start-up costs ($)

f = Annual fixed charges against investment for construction and start-up (15% for depreciation + 1% interest)

I_u = Fabricated value of all uranium inventories at steady-state conditions ($)

I_p = Value of Pu held-up at steady-state conditions ($) = $(\frac{Mg}{2} + LR)\, \emptyset$*

f^1 = Annual fixed charges against I_u and I_p (16% rental or incentive charge)

N = Annual operating cost including personnel, fuel, services, etc. ($/yr)

M = Uranium inventory in target (material being converted) (tons)

g = Fuel processing level (grams/ton)

L = Lag period between product discharge from target and product delivery (yrs)

R = Annual plutonium production at 85% operating factor (grams/yr)

*The use of $\emptyset$ in this equation is somewhat erroneous in that the correct value should correspond to costs incurred for the various Pu inventories at their respective unprocessed states throughout the cycle. However, the slight discrepancy involved by using $\emptyset$ as shown does not justify the complications that would otherwise be involved. The procedure used here is in line with that implied in the AEC ground rules.

3. Values of Cost Components for C-50 Concept

Component	Excluding Chemical Processing	Including Chemical Processing	Reference
C	$181, 309, 000	$206, 200, 000	Appendix B-1, Sec. 1
S	$ 4, 996, 000	$ 5, 600, 000	Appendix B-1, Sec. 8
f	16%	16%	Appendix B-3, Sec. 1b
I_u	$ 3, 030, 000	$ 3, 030, 000	Appendix B-3, Sec. 5a
I_p	$ 292, 300 ∅	$ 309, 200 ∅	(Mg/2 + LR) ∅
f^1	16%	16%	Appendix B-3, Sec. 1c
N	$ 27, 420, 000	$ 29, 430, 000	Appendix B-2
M	462 tons	462 tons	Appendix B-3, Sec. 5b
g	850 grams/ton	850 grams/ ton	Appendix B-3, Sec. 5c
L	0. 17 yrs	0. 20 yrs	Appendix B-3, Sec. 5d
R	564, 000 grams/yr	564, 000 grams/yr	Section 6. 14

4. Computations

By substituting the cost components listed above into the basic formula given in Section 2 of the Appendix, the cost of plutonium has been calculated to be $112 per gram in the unprocessed state and $124 per gram after processing.

5. Supplementary Information on Cost Components

The following is an explanation of those cost components which are not fully defined in other sections of this report:

a. "I_u", Value of Uranium Inventories

This is the sum of: (1) the value as held in initial storage for the secondary target and the target lattice, and (2) the steady-state value in the secondary target and the lattice.

It has been assumed that depleted uranium in the form of UF_6 will be available at no cost. Consequently, in the case of an MTA process, uranium inventory values will reflect only the cost of fabrication and negligible handling costs. Actually, it may be reasoned that fabrication costs for the target and lattice charge, at steady-state, should be treated as a part of plant investment. This has not been done, however, since the fixed charge rates are identical for inventory and plant investment, and since the usual practice in reactor evaluation work is to consider fabrication as a part of uranium costs. Similarly, fabrication costs for initial storage quantities, under tight scheduling assumptions, could be considered as working capital and therefore would be subject to only a 2 per cent fixed charge rate. This approach would not always be realistic, and therefore, these costs have been treated as a part of inventory so as to receive the 16 per cent fixed charge rate.

The calculation used to arrive at the value of uranium inventory is outlined below:

	Amount Tons	Unit Value (Fabrication Only) $ per Ton	Total Value
Secondary Target Initial Storage	99(1)	5840(2)	$ 578,000
Target Lattice Initial Storage	152(1)	6640(2)	$1,010,000
Secondary Target	228(1)	2920(3)	$ 665,000
Target Lattice	234(1)	3320(3)	$ 777,000
I_u, Total Value of Uranium Inventory			$3,030,000

(1) From Figure 11.

(2) From Section 3 of Appendix B-2: Lattice fuel cost $3.32 per lb., Secondary fuel cost $2.92 per lb.

(3) The usual practice in computing the steady-state inventory value of uranium being converted in a reactor is to take the average between its original and depleted values. This procedure gives correct results for the MTA process which amounts to taking one-half of the original fabrication costs.

b. "M" - Uranium Inventory in Target

This is the sum of the 228 tons of uranium in the secondary target and the 234 tons of uranium in the target lattice. These values are shown in Figure 4.

c. "g" - Fuel Processing Level (grams/ton)

This is the average processing level for the 462 total tons of uranium in the target lattice of the secondary target. As discussed in Appendix A, Section A-4 - 2C, the processing level of the secondary target is 1,000 grams per ton and as discussed in Section A-4 - 2D of this appendix the processing level of the target lattice is 700 grams per ton. As mentioned above there are 228 tons of uranium in the secondary target and 234 tons of uranium in the target lattice. Therefore:

$$\frac{228 \times 1,000 + 234 \times 700}{462} = 850 \text{ grams per ton average processing level.}$$

d. "L" - Lag Period Between Product Discharge from Target and Product Delivery (yrs)

The value of 0.17 yrs for this period under the column entitled "Excluding Chemical Processing" is equal to the plutonium held-up in the lag storage (93,000 grams per Figure 11), divided by the production rate of 564,000 grams per year. The value of 0.20 years for this period under the column entitled "Including Chemical Processing" is equal to total of the plutonium held-up in lag storage, chemical separations, and plutonium shipping (114,700 grams per Figure 11) divided by the production rate of 564,000 grams per year.